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Harmonic Measurements of the Galileo Spacecraft X-Band Transmitter System

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Harmonics of X-band (8.4-GHz) spacecraft transmitter systems can be used to measure the performance characteristics of higher frequency deep space communications links. The Galileo X-band transmitter system was measured at the second, third, and fourth harmonics (16.8 GHz, 25.2 GHz, and 33.6 GHz, respectively). The effective isotropic radiated power was determined to be approximately 52 dBm at 16.8 GHz, 47 dBm at 25.2 GHz, and 25 dBm at 33.6 GHz. These values can be useful, depending upon the sensitivity of the Earth-based receiving system and the distance of the spacecraft from Earth.

I. Introduction

There is a need to accurately measure the performance of the Ka-band (33.6 GHz) deep space communications link between a spacecraft and the Deep Space Network (DSN). This must be done prior to making a commitment to use Ka-band as a primary deep space communications frequency. Harmonics of the current X-band (8.4 GHz) spacecraft transmitter system can be used as "beacons" to enable simultaneous relative measurements of Ka-band and X-band link performance with high differential precision.

The Galileo X-band transmitter system was selected for evaluation at the second, third, and fourth harmonics because a spare transmitter and feed system were available. The objective of the evaluation was to determine the effective radiated power provided by the harmonics of the Galileo X-band transmitter system. During September and October 1985, measurements were made to determine the amplitude and phase patterns of the Galileo X-band antenna feed and to compute the maximum effective radiated power and radiation patterns of the overall Galileo antenna and transmitter system at 16.8 GHz (second harmonic), 25.2 GHz (third harmonic), and 33.6 GHz (fourth harmonic).

II. Measurement of Amplitude and Phase Patterns

The transmission line from the traveling wave tube amplifier (TWTA) output to the antenna feed is of sufficient size to pass higher order modes of the X-band transmitter's harmonics. The transmitted power in each of these higher order modes will be extremely dependent on the configuration of the transmission line. For future use with the actual Galileo spacecraft, the geometrical dependence associated with higher order modes required the measurement of an accurate copy of the Galileo X-band transmission system on an antenna pattern range. To help compensate for the small dimensional differences between the flight hardware and this test hardware, the operating frequency was swept from 8395 MHz to 8425 MHz to establish a pattern envelope useful in the selection of representative frequencies for the final measurements. The drive power of the TWTA was varied above and below the normal operating power to reflect the differences between TWTAs. The frequencies of 8415 MHz and 8420 MHz and normal operating power were then chosen for detailed measurements.

A test unit support structure was fabricated and the RF equivalent of the Galileo flight X-band hardware, from the TWTA to the antenna feed, was assembled on it. The near-field antenna facility was instrumented and tested as a far-field range for 16.8 GHz, 25.2 GHz, and 33.6 GHz. A schematic diagram of the test chamber setup is shown in Fig. 1. The test unit was mounted on a rotatable platform with the phase center of the feed antenna on the axis of rotation. The patterns were measured by sliding the probe antenna along a track located above the feed. Data were recorded at various angles of feed rotation with increments of 30 degrees. These data were stored on a digital recorder and later corrected for distance variations and test probe patterns. Far-field amplitude patterns were generated, along with the absolute power reference, so that they could be integrated to obtain the total available harmonic power.

The phase patterns of the Galileo X-band feed antenna were needed to complete the data required to compute the effective radiated power of the overall antenna/transmitter system. These phase and amplitude patterns were recorded simultaneously.

III. Calculations of Antenna Radiated Power

The overall antenna effective isotropic radiated power (EIRP) was predicted using the feed pattern measurements. To effectively use the Galileo Ka-band signal for link comparison with X-band, an EIRP of at least 30 dBm is considered necessary for satisfactory reception on Earth. The EIRP is predicted by computation of the overall antenna normalized gain pattern (with respect to the feed) and the feed power measurement. Then the EIRP calculation is modified by the spacecraft antenna reflector mesh loss as well as the subreflector dichroic loss at the frequencies of interest.

The geometry of the Galileo high-gain antenna is shown in Fig. 2. Both the main reflector and the subreflector are shaped surfaces. The feed pattern was measured (as described in previous sections) over 12 azimuthal cuts (phi-cuts) for small but uneven increments in polar angle (theta). These data were first reduced to obtain the feed pattern for every 0.5 degree in theta direction over all the phi-cuts. Then the Cassegrainian reflector system was replaced with an equivalent paraboloid (Ref. 1). This yields a good approximation for the overall antenna pattern while saving considerable time and computer costs. For the equivalent paraboloid, the dish diameter is the same as the main reflector diameter (D = 188.8 in. or 479.55 cm) and the effective focal distance was calculated to be F_e = 195.22 in. or 495.86 cm. The far-field pattern of the paraboloid was computed using a modified version of the physical optics/Jacobi-Bessel polynomial expansion program.[1] This program was developed for circularly symmetric feed patterns; however, for this case, the feed pattern for harmonic frequencies is not circularly symmetric. Therefore, the PATRN subroutine of Rahmat-Samii (Footnote 1) was modified to generate the feed pattern, at any point required by the program, via a two-dimensional interpolation of the feed measured data. Using this program, the far-field patterns of the Galileo antenna for second, third, and fourth harmonics of 8415 and 8420 MHz were computed. The phi = 0 cut patterns for the above frequencies are shown in Figs. 3 through 8. These patterns represent the normalized antenna gain relative to the feed gain, i.e., they are computed by assuming zero gain for the feed boresight. It can be seen that the higher the frequency is, the more lobes are generated near the boresight. This is due to the interaction of a larger number of propagating modes at higher frequencies.

To find the feed radiated power, its RF pattern was measured relative to a known reference antenna. This was accomplished by moving a probe in front of the reference and the test (Galileo feed) antennas. In this measurement, the far-field patterns of both antennas, as well as the input power of the reference horn, were found. Taking into account the distance between the probe and the reference and test antennas, the overall EIRP can be determined. The results are shown in Table 1. Considering the 30-dB minimum EIRP requirement, it is evident that the fourth harmonic output of the antenna would not be useful at a distance greater than 1 AU, but the second and third harmonic signals should provide more than enough power for accurate measurements.

IV. Losses

The reflector mesh of the Galileo high-gain antenna is identical to the tracking and data relay satellite (TDRSS) antenna built by the Harris Corporation. For the TDRSS antenna, the peak gain loss (compared to a solid reflector),

[1]Rahmat-Samii, Y., *Offset Parabolic Reflector Computer Program for Analysis of Satellite Communication Antennas*, JPL document D-1203, Jet Propulsion Laboratory, Pasadena, CA, Dec. 1983 (JPL internal document).

as a function of frequency, is computed and shown in Fig. 9.[2] It can be seen that the mesh loss for the second and third harmonics of the Galileo transmitter (16.8 GHz and 25.2 GHz) are approximately 0.5 dB and 1.22 dB, respectively; these losses would not reduce the EIRP of the antenna significantly.

Test samples of dichroic subreflector material were measured in the laboratory and found to have reflection loss of between 3 and 6 dB, between 18 and 40 GHz. Phase shift as a function of incident angle was not measured. Making a gross simplification by ignoring the phase, the dichroic reflected power loss is included in the final EIRP given in Table 1.

[2]Rahmat-Samii, Y., and Lee, S. W., *Vector Diffraction Analysis of Mesh Reflector Antennas for Space and Ground Applications*, JPL document D-1573, Jet Propulsion Laboratory, Pasadena, CA, May 14, 1984 (JPL internal document).

V. Conclusions

The second, third, and fourth harmonic effective radiated power of Galileo's X-band transmission system was computed based on measurements of the transmitter and feed system without main or subreflector. The results of this study indicate useful EIRPs at the second and third harmonics. The fourth harmonic EIRP is too low to be considered useful at the distance planned for the Galileo mission. The results are sufficiently encouraging to consider this approach for other missions such as Magellan, where the distance from Earth will vary from 0.3 AU to 1.7 AU.

Acknowledgment

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References

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2. Agrawal, V. D., and Imbriale, W. A., "Design of a Dichroic Cassegrain Subreflector," *IEEE Trans. Antennas and Propagation*, Vol. AP-27, No. 4, pp. 466–473, July 1979.

Table 1. Effective isotropic radiated power (EIRP)

Frequency	EIRP w/o Mesh or Subreflector Loss, dB	Mesh and Subreflector Loss, dB	EIRP w/Mesh and Subreflector Loss, dB
33.660	32.0	5.1 to 8.1	26.9 to 23.9
33.680	32.0	5.1 to 8.1	26.9 to 23.9
25.245	54.4	4.2 to 7.2	50.2 to 47.2
25.260	52.0	4.2 to 7.2	47.8 to 44.8
16.830	57.7	3.5 to 6.5	54.2 to 51.2
16.840	56.7	3.5 to 6.5	53.2 to 50.2
8415	96.3	0	96.3

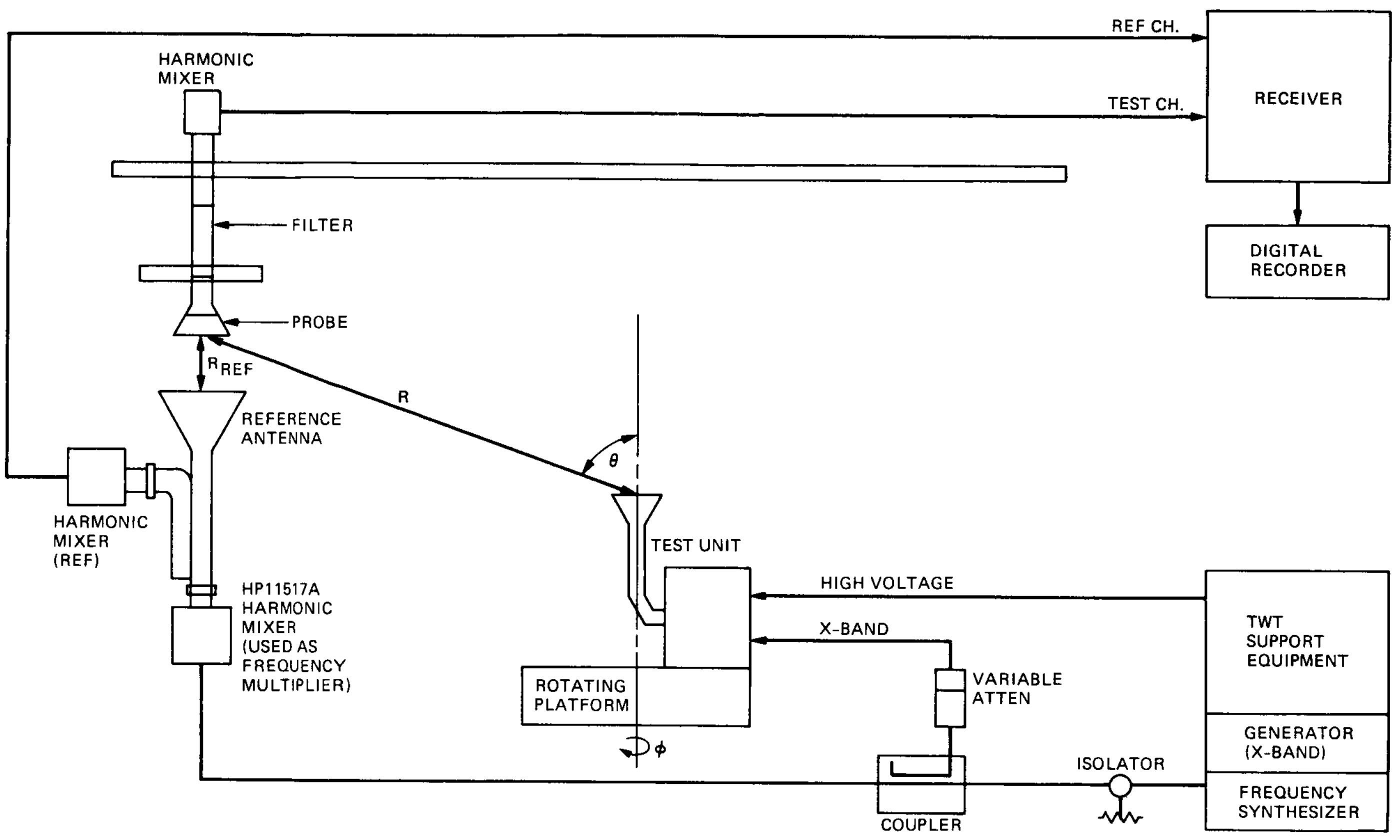

Fig. 1. Near-field facility setup for far-field radiation pattern measurements

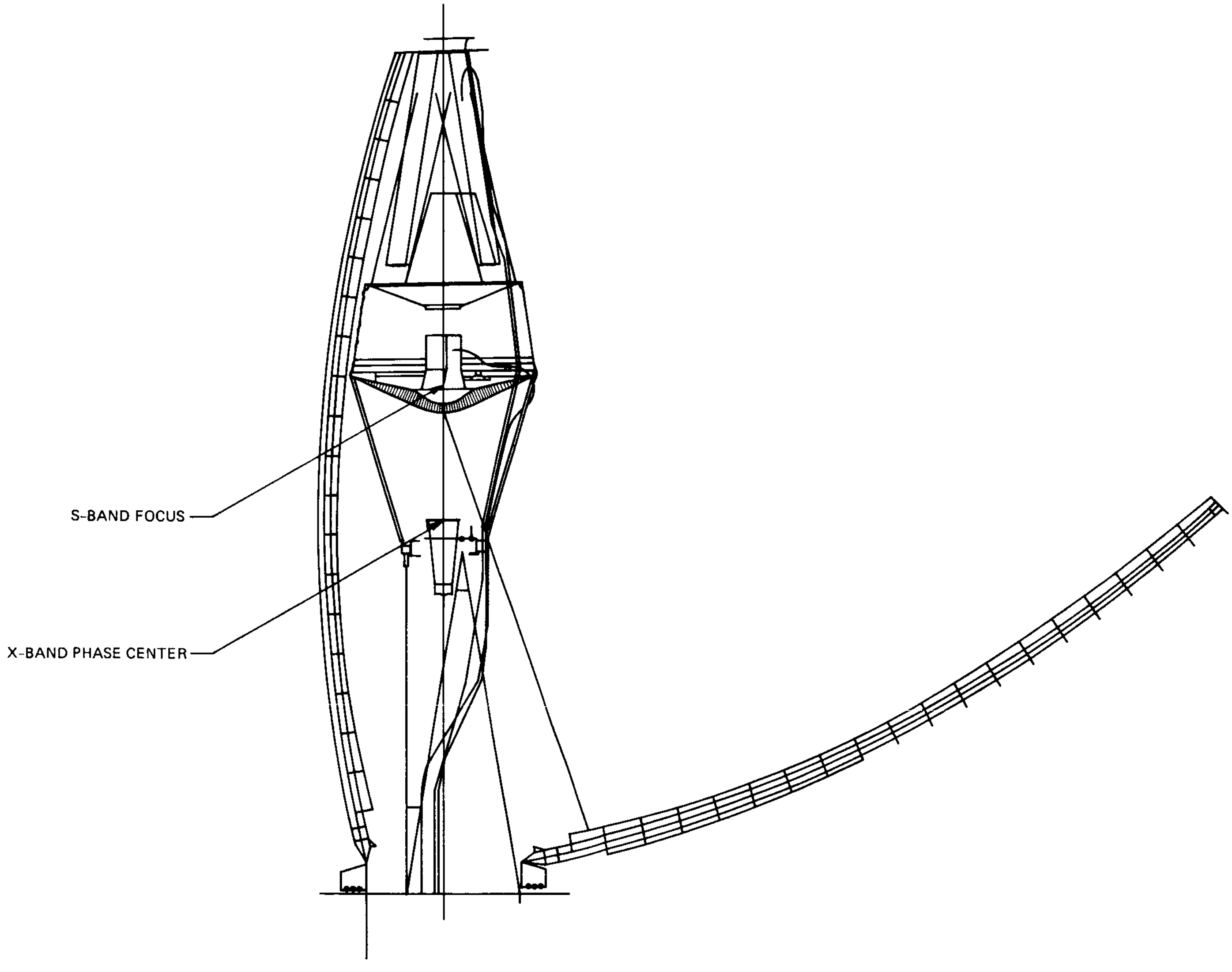

Fig. 2. Galileo HGA configuration

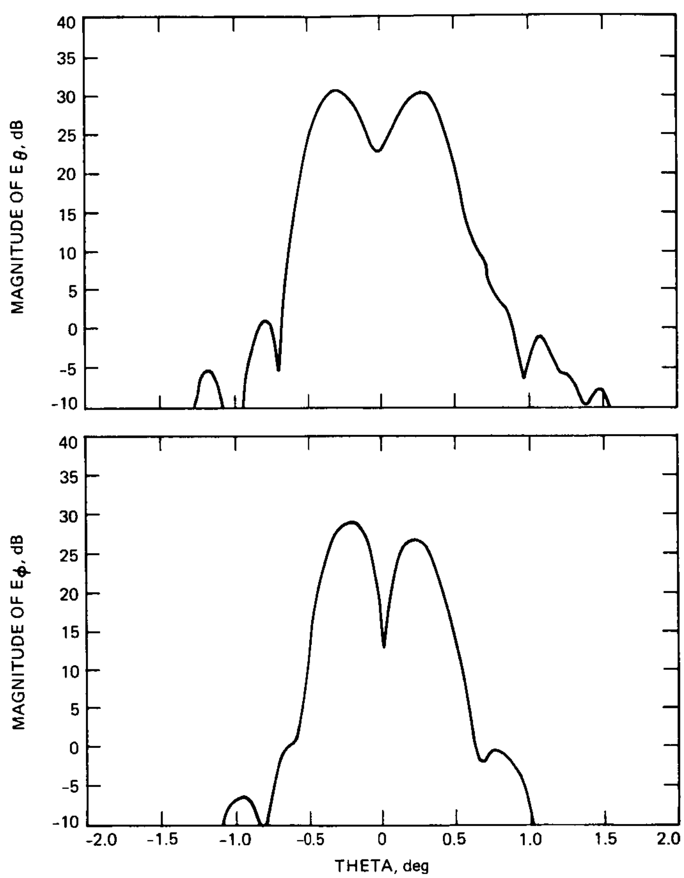

Fig. 3. Far-field patterns for $\phi = 0$ degree plane at second harmonic of 8415 MHz

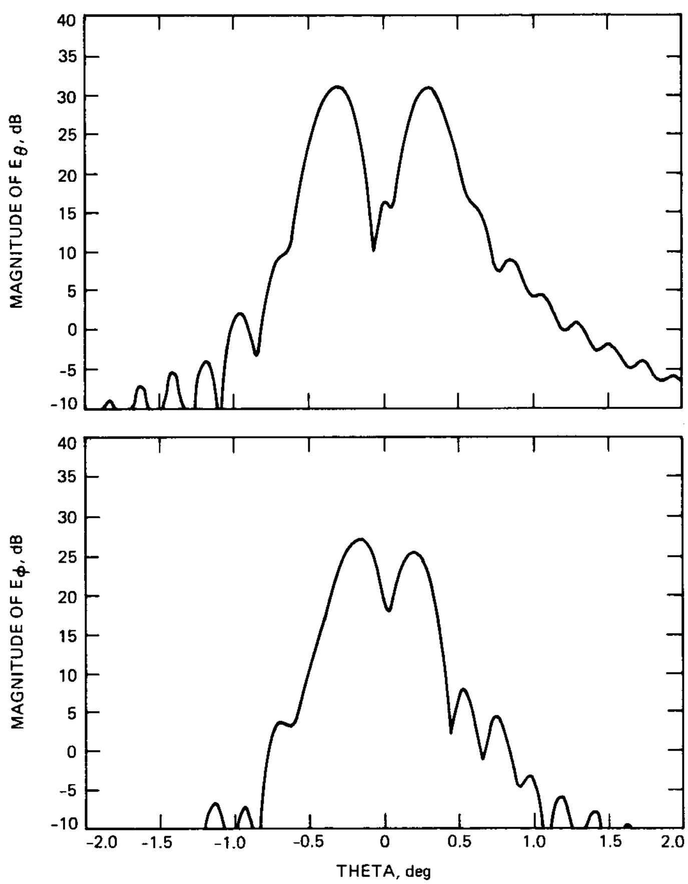

Fig. 4. Far-field patterns for $\phi = 0$ degree plane at second harmonic of 8420 MHz

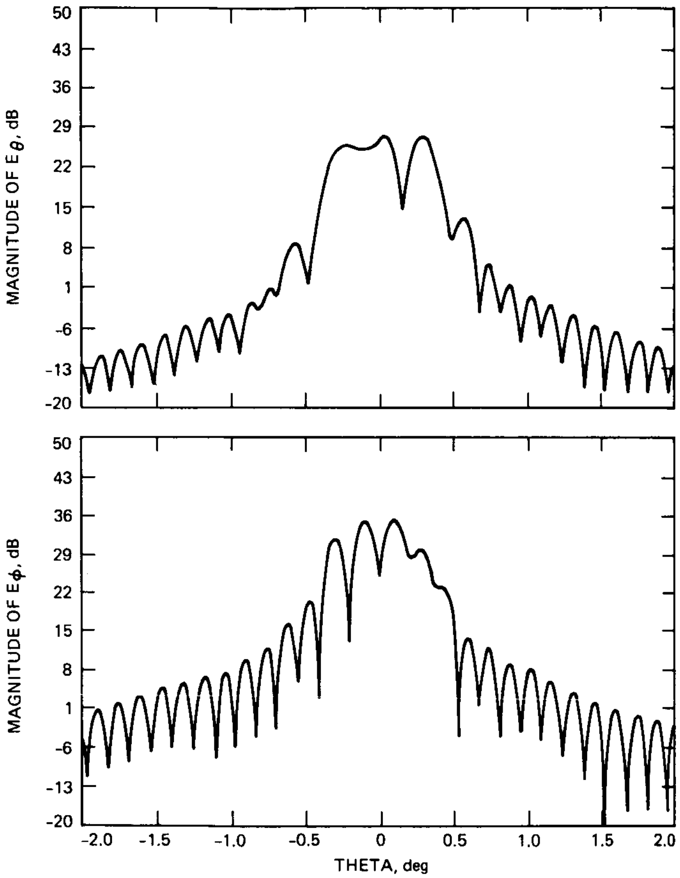

Fig. 5. Far-field patterns for ϕ = 0 degree plane at third harmonic of 8415 MHz

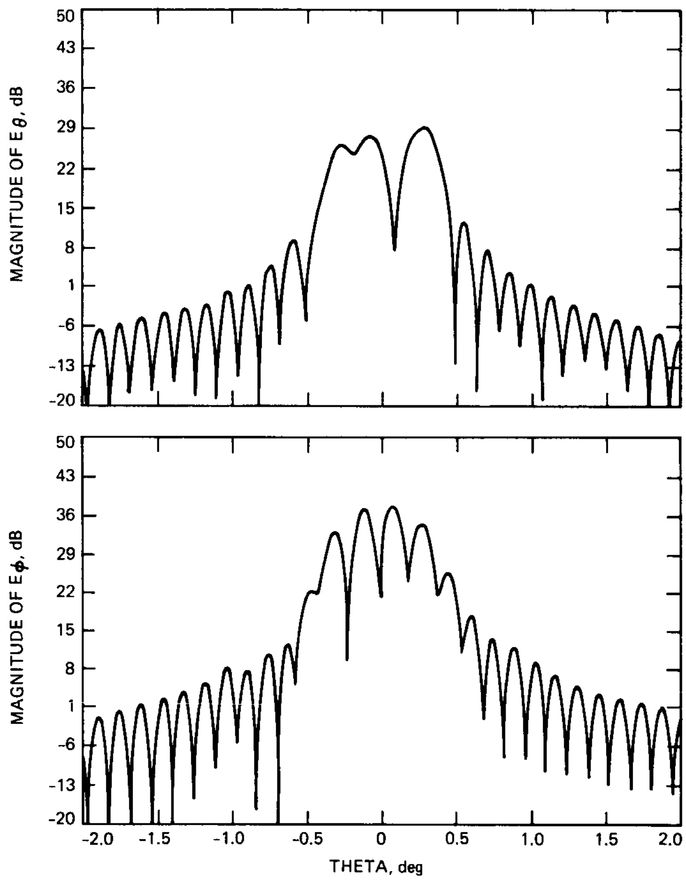

Fig. 6. Far-field patterns for ϕ = 0 degree plane at third harmonic of 8420 MHz

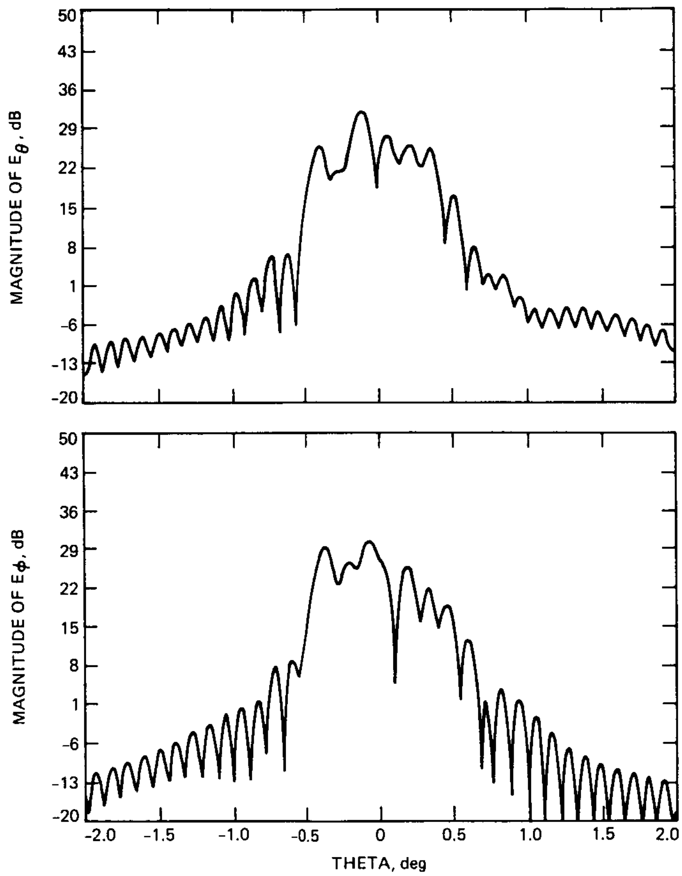

Fig. 7. Far-field patterns for ϕ = 0 degree plane at fourth harmonic of 8415 MHz

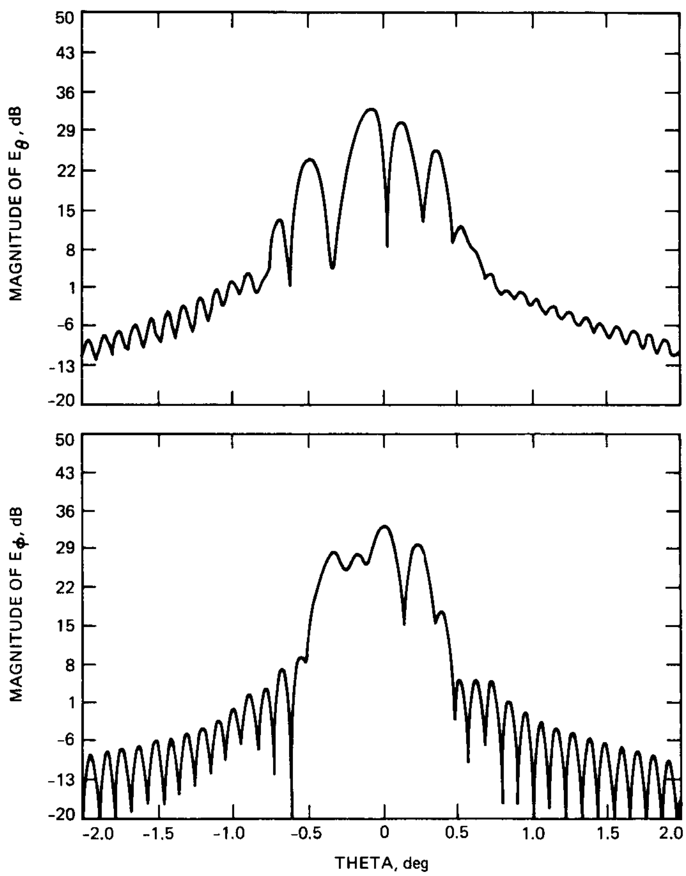

Fig. 8. Far-field patterns for ϕ = 0 degree plane at fourth harmonic of 8420 MHz

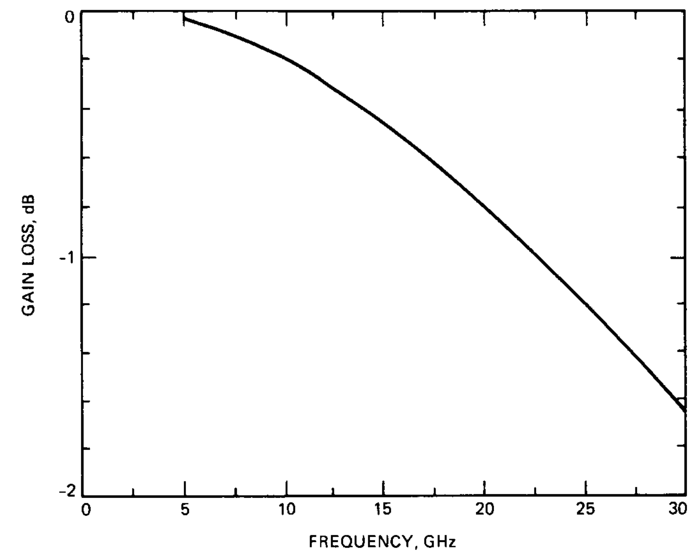

Fig. 9. Boresight gain loss vs frequency for TRDSS mesh parameters